Engineering Note
for
E906 Detector Assembly

PROJECT: E906

TITLE: Station 1X Hodoscope Assembly

AUTHOR: Tom O'Connor – Argonne National Laboratory

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REVIEWER(S): Kevin Bailey – Argonne National Laboratory

ABSTRACT: This document describes an aluminum framework designed to secure and install a hodoscope array in E906. Once assembled this framework will be attached to an I-beam and hung in the E906 beamline.

DESIGN:

The hodoscope arrays for the station 1X hodoscope are provided by UIUC. Each array is composed of 23 scintillators/phototubes mounted to a C-channel aluminum frame. The C-channels (McMaster Carr part number 9001K13) are composed of 6063 aluminum with a base width of 4", leg length of 1", and a wall thickness of 0.125". The channels are secured to each other at each end with aluminum blocks and ¼-20 screws. Figure 1 shows the empty frame and Figure 2 shows the fully assembled hodoscope array.

For the Station 1X hodoscope, two of these arrays will be placed end-to-end to form a detector approximately 54" x 62". When placed into the beamline the scintillators will be oriented vertically. The arrays will be held in place by a framework consisting of aluminum extrusions and fastening hardware. The extrusions and fasteners, produced by 8020 Inc., are shown in Figure 3 and the final assembly for the E906 beamline is shown in Figure 4. The perimeter of the framework is constructed from 1030 and 1010 extrusions. The vertical members consist of a 1030 extrusion coupled to a 1010 extrusion, in 8 places, via the 4015 corner brackets (Fig. 3). The horizontal members consist of 1030 extrusions which are attached to the vertical members via the 4251 slotted corner brackets (Fig. 4). The arrays will be secured to the framework by clamping the connector blocks on the C-channels, in 4 locations, to the 1010 components of the vertical members via the 4119 corner brackets (Fig. 4). The top of the 8020 framework is attached to an aluminum I-beam (S8 x 6.35) which will be used to hang the detector in the E906 beamline.

During assembly, the hodoscope arrays, 8020 extrusions, and I-beam will be laid out horizontally. After assembly the entire package shown in Figure 4 will be lifted and rotated to be installed vertically into the E906 beamline. Table 1 lists the mechanical properties of the extrusion used in this framework.

Part No.	Cross Section	Area (in^2)	Material	lbs/foot	Ix (in^4)	Iy (in^4)
1010	1" x 1"	0.4397	6105-T5*	.5097	0.0442	0.0442
1030	1" x 3"	1.1596	6105-T5*	1.3498	0.9711	0.1238

- UTS = 38ksi minimum, Yield = 35ksi minimum, Emod = 10.2e6 psi,
- Allowable Tensile Stress = 19.5ksi*

*(per Aluminum Design Manual Part IA, 1994).

Table 1 – Mechanical Properties of 8020 Extrusions in 1X Hodoscope Assembly per 8020 Fractional Parts Catalog – 16th edition

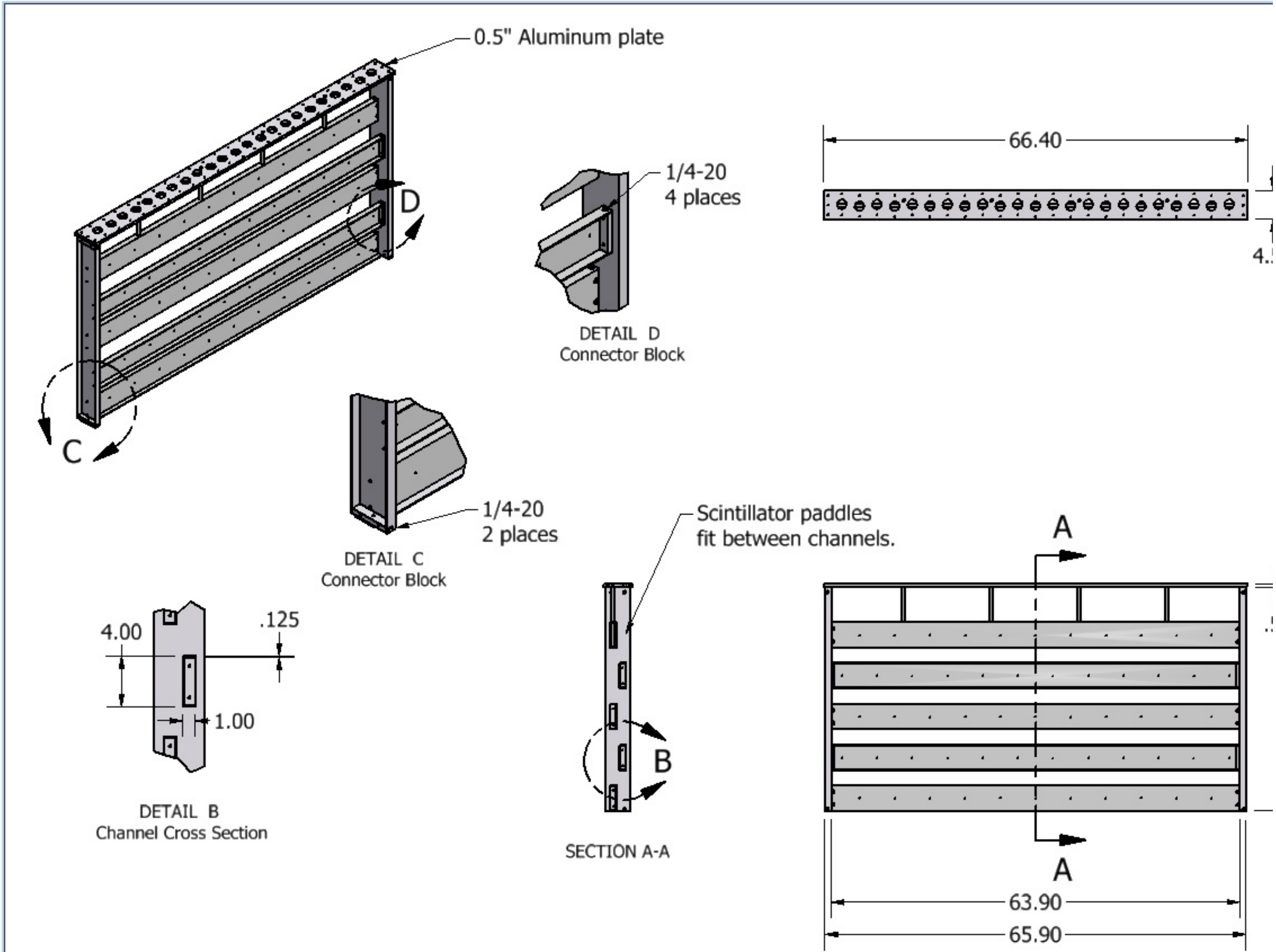


Figure 1: Aluminum Frame for 1X Hodoscope Array

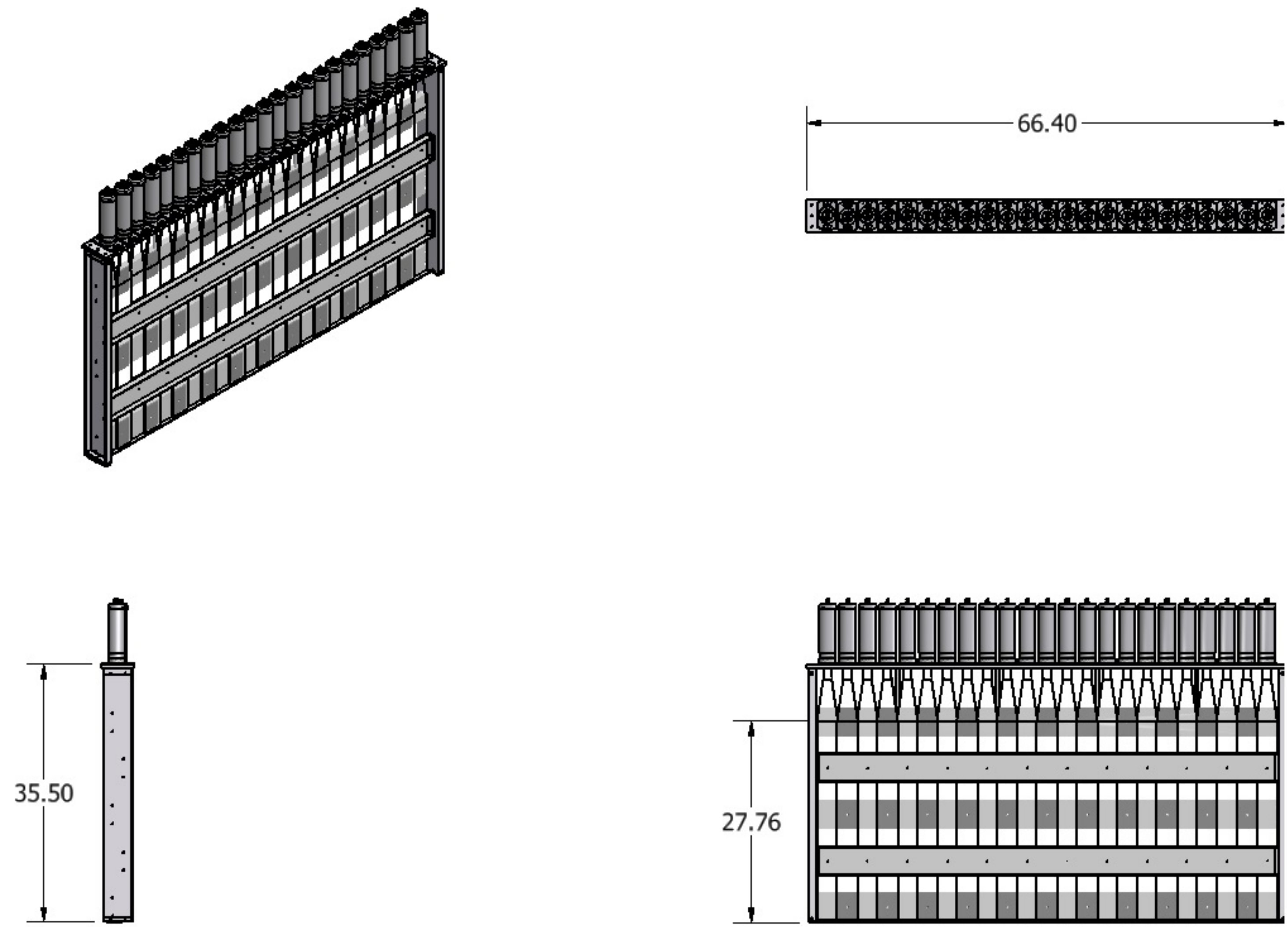


Figure 2: Station 1X Hodoscope Array
(23 scintillators total)
Approximate Total Weight = 112 lbs.

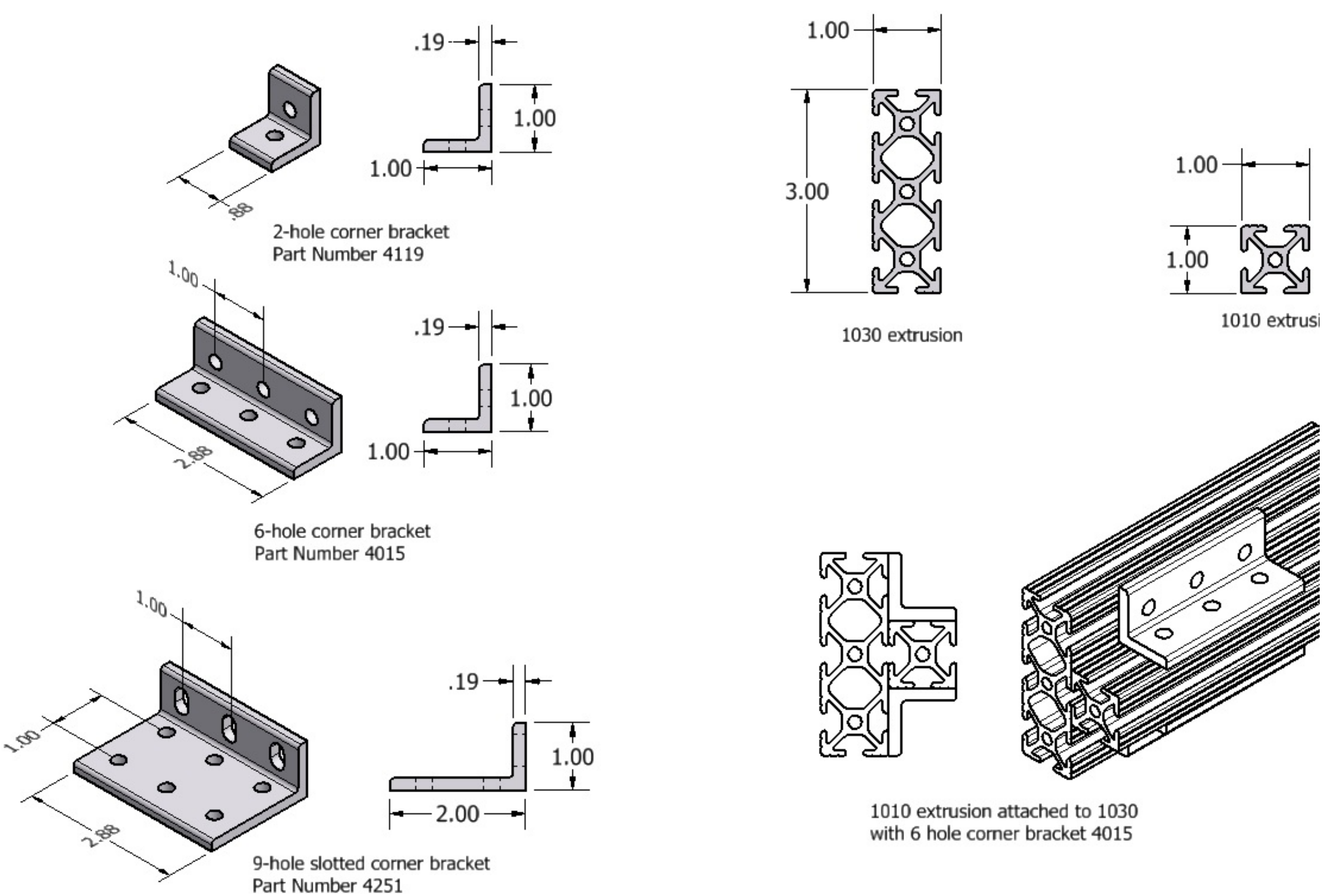


Figure 3: 8020 components used in 1X

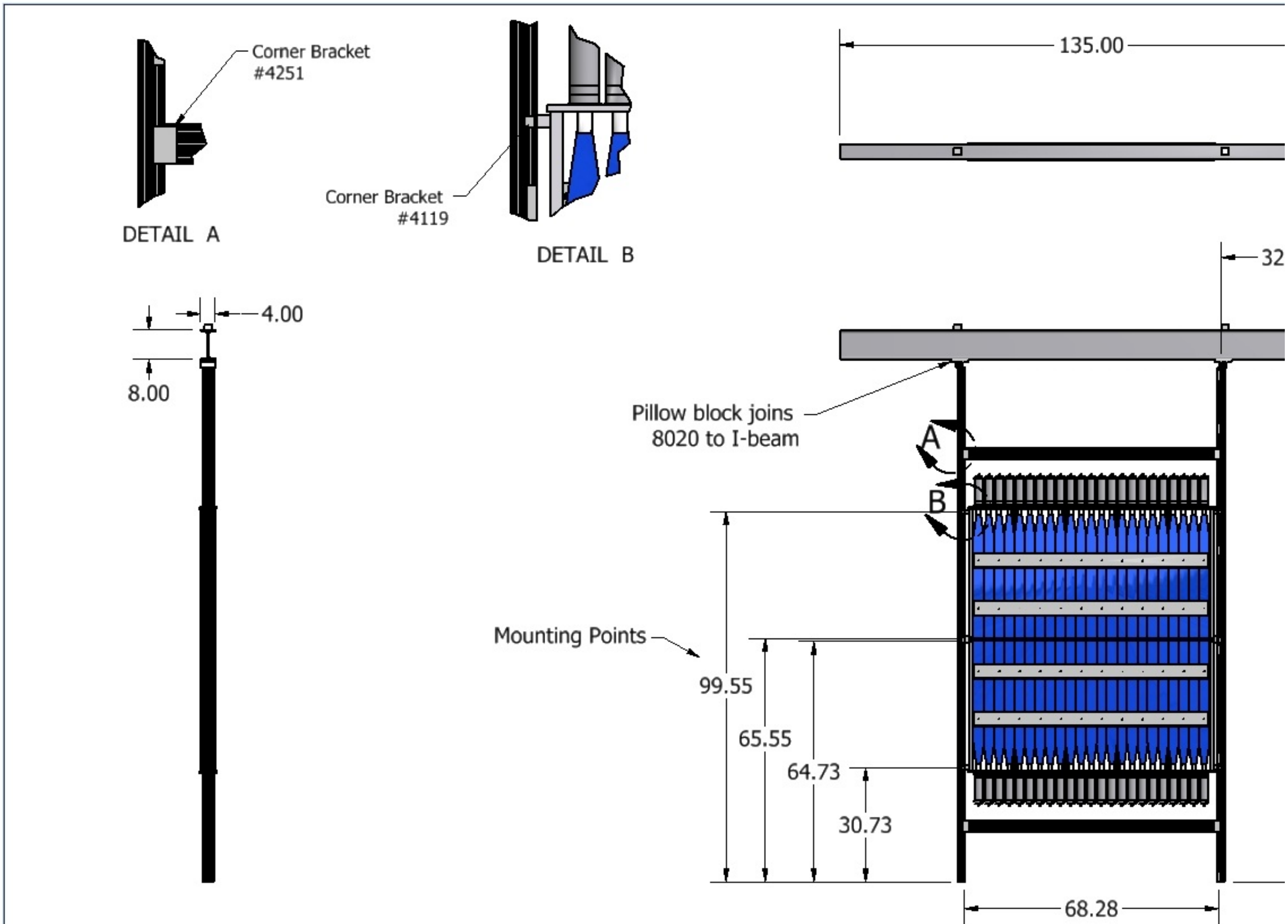


Figure 4: Station 1X Hodoscope Assembly
(46 scintillators total)

ANALYSIS:
The hodoscope array will be built horizontally and then lifted/rotated and installed vertically in the E906 beamline with the tubes oriented vertically. This will be done by wrapping slings around the I-beam and using the crane in NM4. The assembly must be strong enough to withstand the rotation from horizontal to vertical and also be strong enough to hang vertically for the duration of the experiment. Each of these cases is treated separately as follows:

Lifting/Rotating:
When the array assembly is horizontal it can be lifted at one edge (by the I-beam) and re-oriented to the vertical. If the assembly is supported along the top and bottom edges then the weight of the scintillators is essentially borne by two 1030 extrusions. If treated as beams supported on both ends subject to concentrated loads at the locations shown in Figure 4, then the stress and deflection of each load can be calculated using standard formulas:

Stress at any point along the beam: $s = \frac{-Wb}{ZL}x$; for $0 \le x \le a$ **(1)**

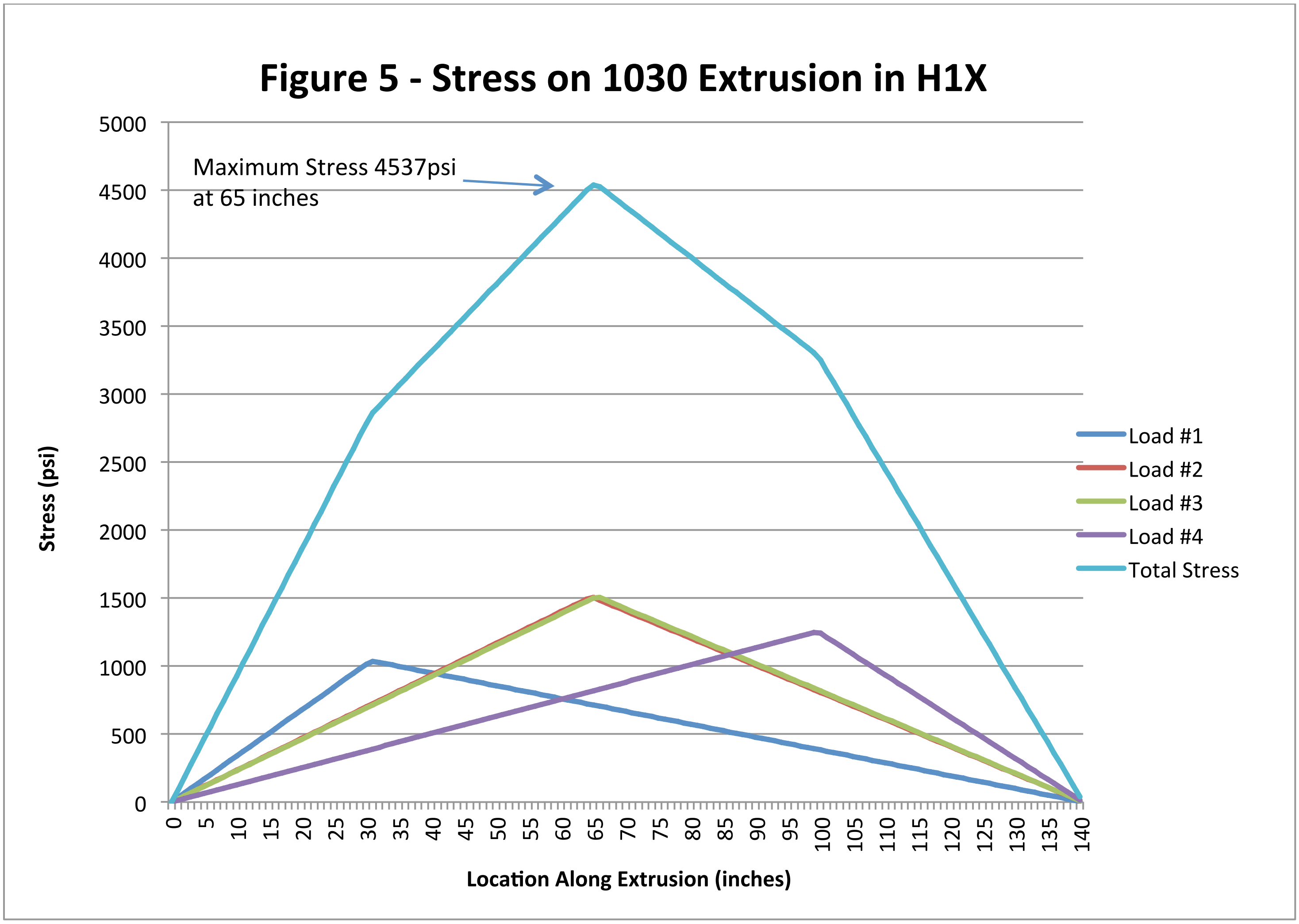
$$s = \frac{-Wa}{ZL}(L - x); \quad \text{for } a \le x \le L \qquad \textbf{(2)}$$

Deflection at any point: $y = \frac{Wbx}{6EIL}(L^2 - b^2 - x^2)$; for $0 \le x \le a$ **(3)**

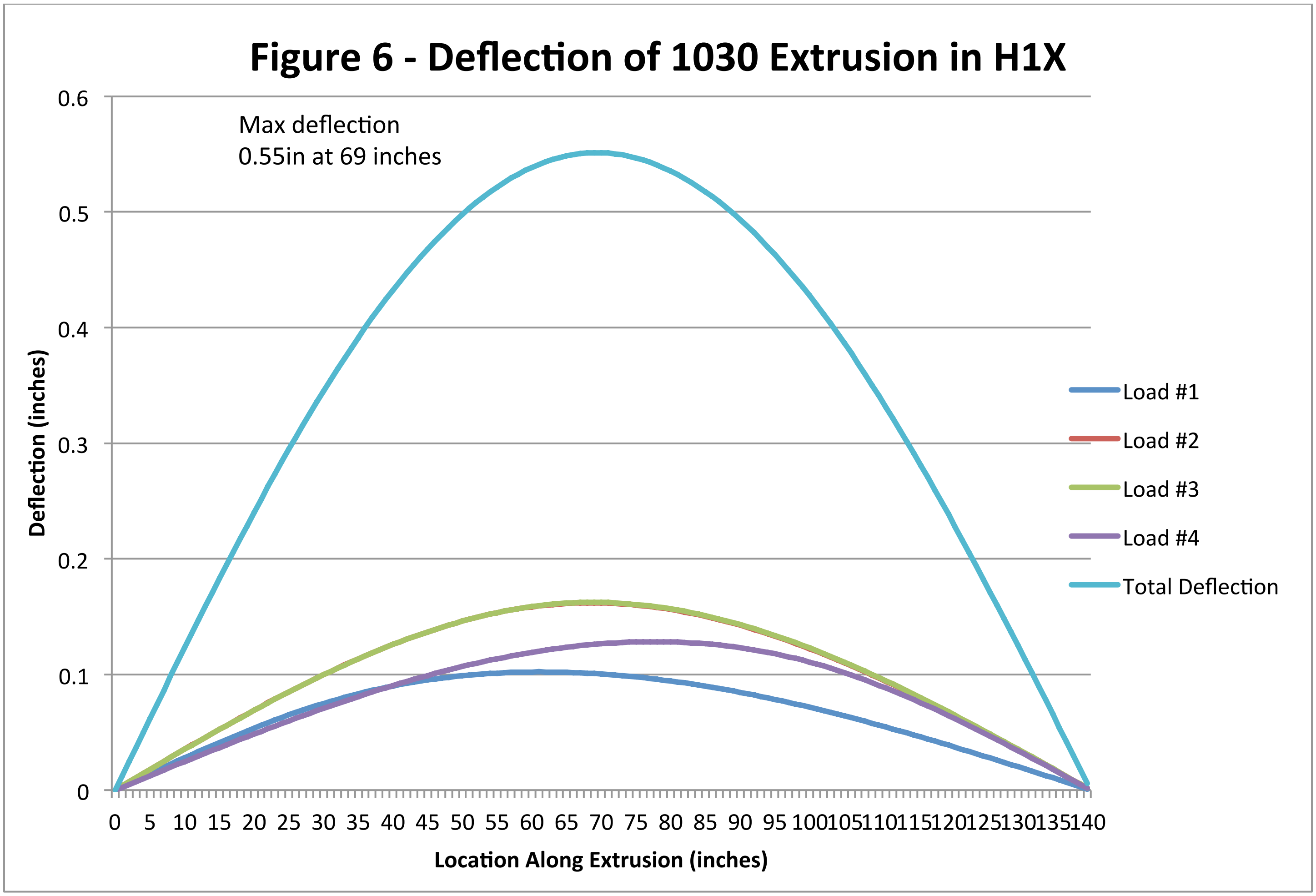
$$y = \frac{Wa(L - x)}{6EIL}[L^2 - a^2 - (L - x)^2]; \text{ for } a \le x \le L \qquad \textbf{(4)}$$

Where:
W is the weight applied at the mounting point (28lb)
L is the length (140.5 inches)
a is the distance from the bottom end to the load
b is the distance from the load to the top end
x is the point in question
I is the moment of inertia, 0.9711in^4
Z is the section modulus (I/1.5in = 0.6474in^3)
E is the modulus of elasticity

Solving Equations (1) and (2) for each individual load and adding the results gives a maximum stress of 4,537psi at a distance of 65 inches from the bottom. A graph of these stresses is shown in Figure 5. The Allowable Bending Stress for a 1030 extrusion with a length of 140.5" (per Aluminum Design Manual Part IA, 1994) is 20,940psi. The maximum stress of 4051psi, when compared to this value for Allowable Bending Stress, provides a safety factor of 20940/4537 = 4.62 and is acceptable.



Likewise, solving Equations (3) and (4) for each individual load and adding those results gives a maximum deflection of 0.55 inches at a distance of 69 inches from the bottom. See Figure 6. This deflection occurs at the start of rotation and will fall to zero as the detector is made vertical and is acceptable.



Two aluminum pillow blocks are used to attach the vertical members of the hodoscope assembly to an aluminum I-beam (S8 x 6.35). See Figure 7. Each pillow block is attached to a 1030 cross section using three screws with ¼-20 threads. They are also attached to the I-beam using four 3/8-16 bolts. At the start of rotation each ¼-20 screw (6 screws total) will experience a shear of roughly 45.8-lbs which will vanish as the array is rotated. With a minor diameter of 0.1887 and an area of 0.0280in^2, the resulting shear stress in each ¼-20 screw is 1636psi. Likewise, at the start of rotation each 3/8-16 bolt (8 bolts total) will experience a shear of roughly 34.4-lbs which will vanish as the array is rotated. With a minor diameter of 0.2970 and an area of 0.069-in^2, the resulting shear stress in each 3/8-16 screw is roughly 499psi. Grade 5 screws with yield strength of 92ksi (per SAE J429) are readily available. Assuming shear strength is 60% of yield strength results in shear strength of 55ksi which is far in excess of these expected actual values.

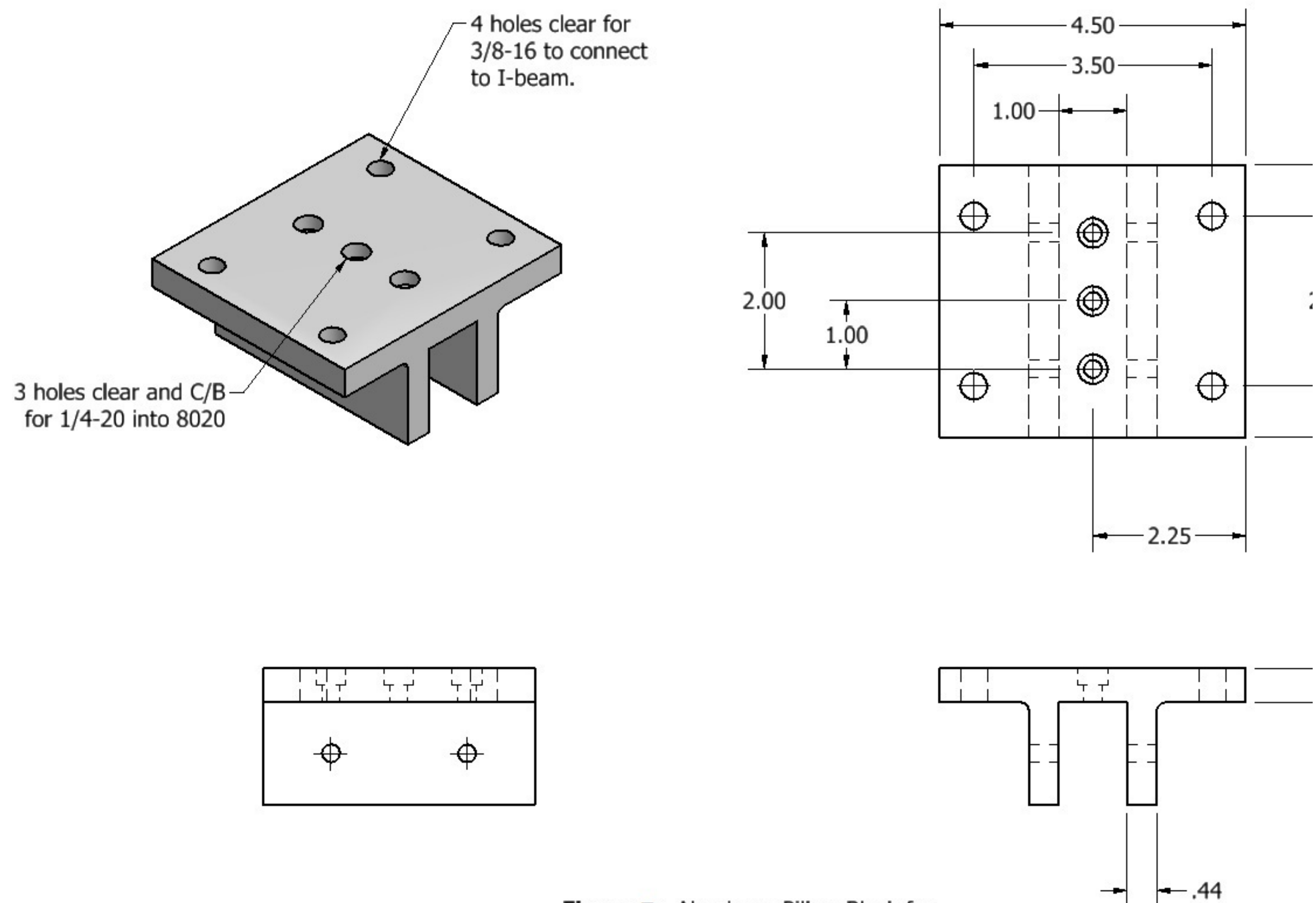


Figure 7: Aluminum Pillow Block for

Placement in E906 Beamline:
Once the detector assembly is vertical the weight of the hodoscopes is borne by two 1030 extrusion that run vertically along the edges of the framework. With an area of 1.1596in^2 (Table 1) and a weight per column of 137.5-lbs, the tensile stress on each vertical extrusion is 137.5/1.1596 = 119psi and is not a cause for concern when compared to the allowable tensile stress of 19.5ksi.

This hodoscope will be inserted into the beam line by resting the ends of the bottom surface of the aluminum I-beam onto the top surface of a pair of cantilevered steel I-beams that have been welded onto the top of a nearby magnet and are perpendicular to the plane of the array. The design of the welded steel I-beam structure will be addressed in a separate engineering note. Once in place this aluminum I-beam will experience stress and deflection from the weight of the hodoscope. If treated as a beam supported on both ends subject to concentrated identical loads equidistant from center then the stress and deflection of the I-beam can be calculated using standard formulas:

Stress at center of constant cross section: $s = \dfrac{-Wa}{Z}$ **(5)**

Maximum deflection at center: $y = \dfrac{Wa}{24EI}(3L^2 - 4a^2)$ **(6)**

Where:
- W is the weight or each load (137.5lb)
- L is the length of the beam(135 inches)
- a is the distance from the end to the load (32.5 inches)
- I is the moment of inertia of S8x6.35 beam (57.6in^4)
- Z is the section modulus
- E is the modulus of elasticity

Substituting the values from Table 1 into equation (2) yields:

$$s = -\frac{137.5lb \times 32.5in}{\left(57.6in^4 \big/ 4in\right)} = -310.3lb/in^2$$

Likewise, substituting the values into equation (3) yields:

$$y = \frac{1}{24}\left[\frac{137.5lb \times (32.5in)}{10.2e6psi \times 57.6in^4}\right]\left[3(135in)^2 - 4(32.5in)^2\right] = 0.016in$$

The bending stress of 310.3psi and deflection of 0.016in of the S8x6.35 I-beam are not a cause for concern.

Finally, in the beam line the weight of the entire array/framework assembly is held by the six ¼-20 screws and eight 3/8-16 in tension. Each ¼-20 screw experiences a tensile force of roughly 45.8-lbs. With a tensile stress area of 0.0318in^2, the resulting tensile stress in each ¼-20 screw is 1440psi. Likewise, each 3/8-16 screw experiences a tensile force of roughly 34.4-lbs. With a tensile stress area of 0.0774in^2, the resulting tensile stress in each 3/8-16 screw is 444psi. These are acceptable stresses for Grade 5 screws per SAE J429.